United States Patent [19]

Stevens

[11] **3,763,844**

[45] **Oct. 9, 1973**

[54] **APPARATUS AND METHOD FOR DRESSING GRINDING WHEELS**

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[22] Filed: **July 8, 1971**

[21] Appl. No.: **160,867**

[52] **U.S. Cl.** ..... **125/11 PH,** 51/165.87

[51] **Int. Cl.** **B24b 53/08**

[58] **Field of Search** ..... 125/11 R, 11 CW, 125/11 PH, 11 TP, 11 H, 11 NT; 51/169.87

[56] **References Cited**

UNITED STATES PATENTS

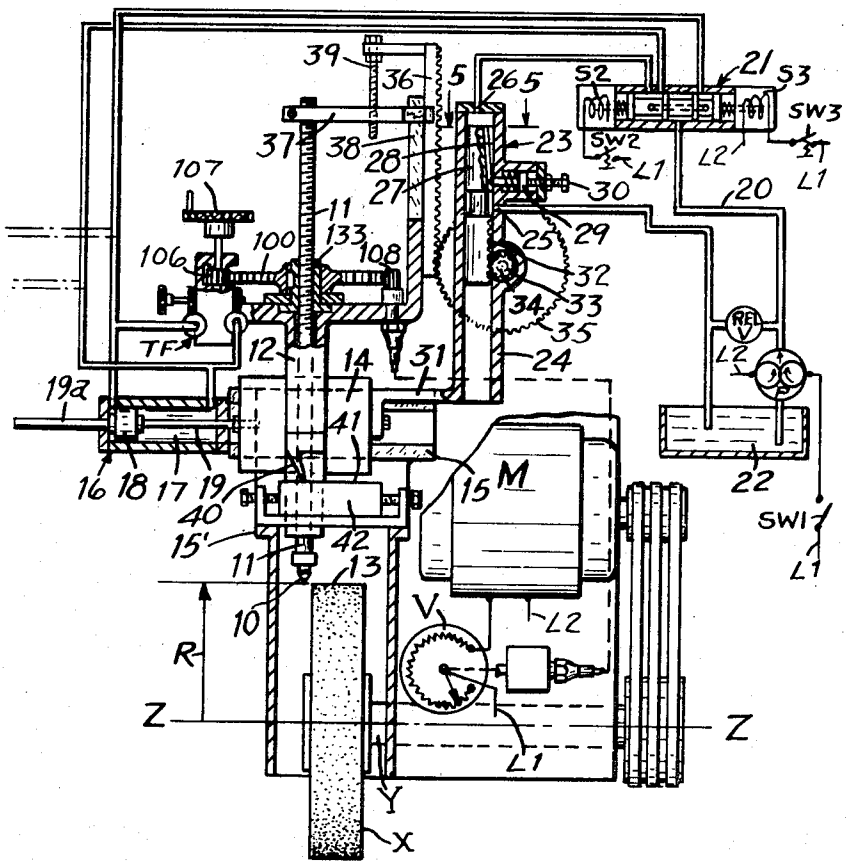
2,648,172	8/1953	Silven	51/5
2,697,426	12/1954	Price et al.	125/11 PH
3,033,187	5/1962	Wespi	125/11 CW
3,429,305	2/1969	Hall	125/11 R

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Assistant Examiner—N. P. Godici
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[57] **ABSTRACT**

Method and apparatus for truing or dressing a grinding wheel which is rotated at a progressively increasing angular velocity to compensate for decreasing wheel diameter so that a constant peripheral wheel speed is maintained, the speed of traverse of the dressing tool along the grinding face of the wheel is controlled in accordance with wheel diameter. This is achieved by means responsive to any change in the radial position of the dressing tool with respect to the wheel axis, and controlling the traverse speed of the truing tool accordingly, so that for a particular sequence of repetitive grinding operations the traverse speed is inversely proportional to the wheel diameter, whereby the grinding face is repeatedly dressed to substantially a uniform surface finish during the useful life of the grinding wheel.

19 Claims, 5 Drawing Figures



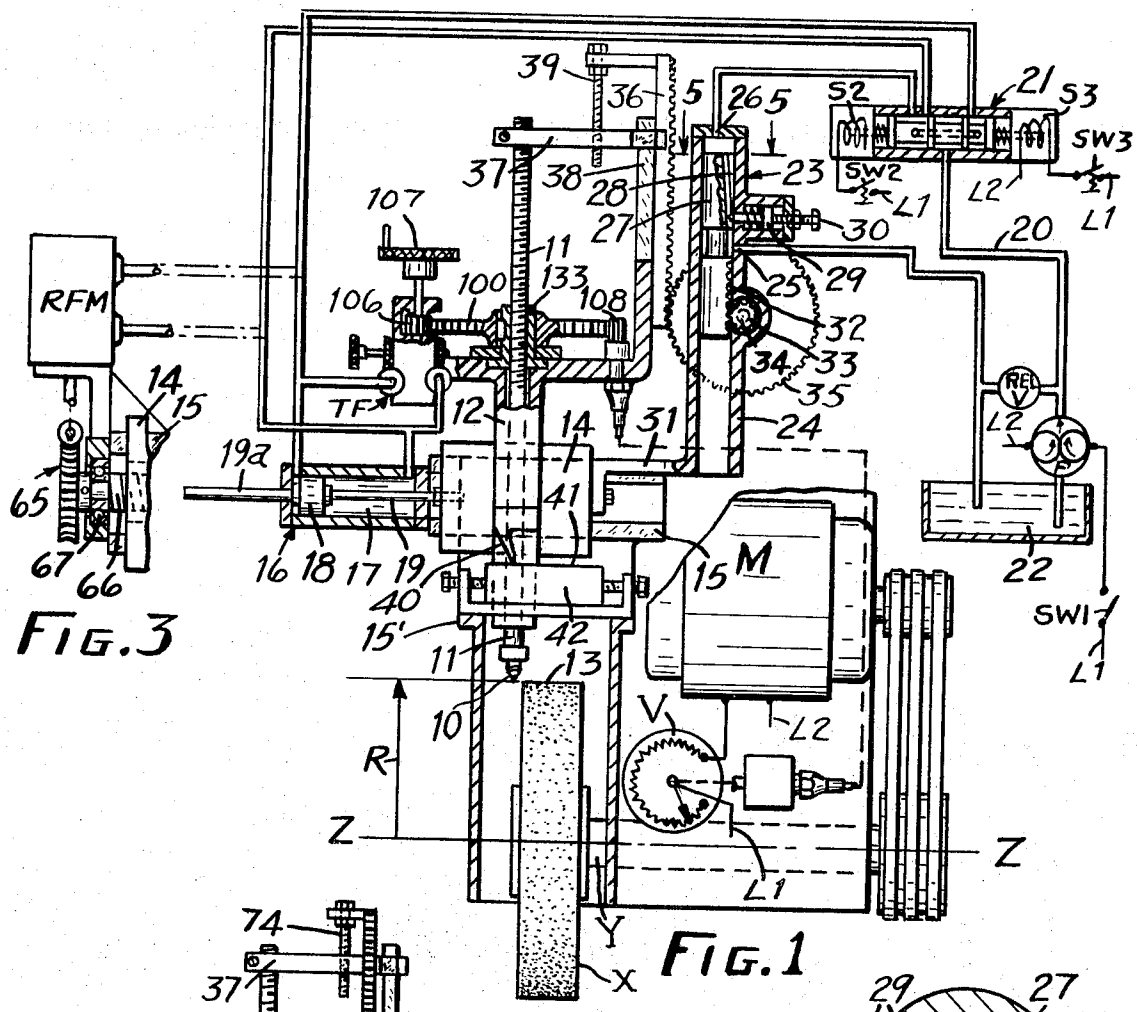


FIG. 3

FIG. 1

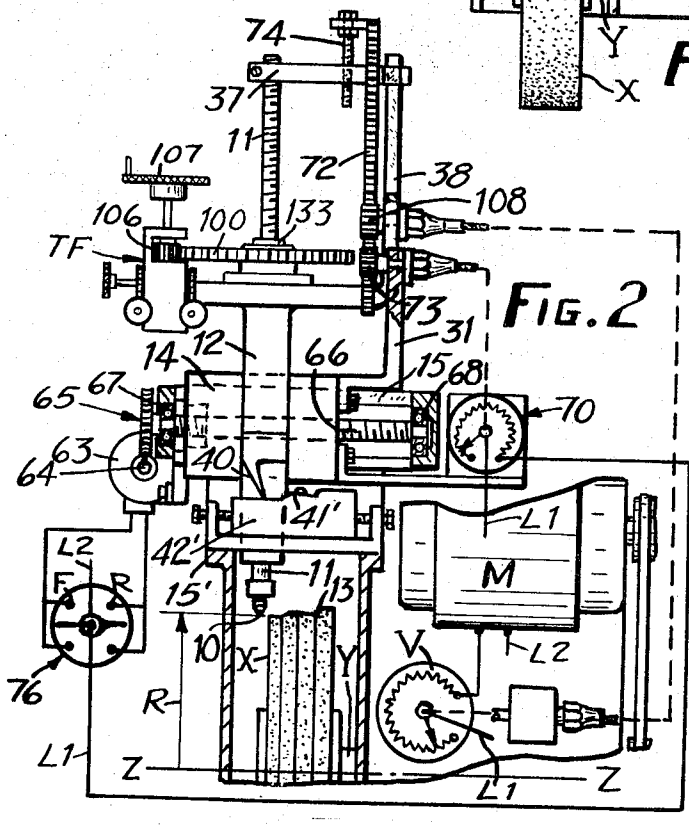


FIG. 2

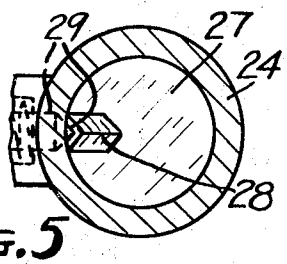


FIG. 5

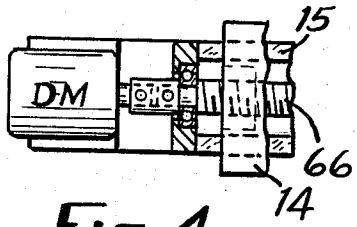


FIG. 4

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APPARATUS AND METHOD FOR DRESSING GRINDING WHEELS

BACKGROUND OF THE INVENTION

1. Field of Invention

This invention relates generally to precision grinding machines of the kind used to perform identical repetitive grinding operations on a series of workpieces, and in which the grinding wheel is rotated about an axis at a progressively increasing angular velocity in accordance with decreasing wheel diameter so as to maintain a constant peripheral wheel speed. The invention relates particularly to a method and device for dressing or truing of grinding wheels in such machines.

2. Description of the Prior Art

In the art of grinding it is well known that proper wheel truing or dressing is an important factor in determining the load on the grinding wheel, the surface finish of the ground workpieces, the rate of removal of waste material, and the grinding ratio, and that the condition or finish of the dressed face of the wheel depends upon the velocity of traverse of the dressing tool across the wheel face. Hitherto it has been the common practice first to determine the optimum dressing speed for a particular grinding operation and thereafter let the dressing speed remain fixed. This practice has certain disadvantages for as the wheel diameter decreases, the fixed speed changes the truing tool pitch pattern and hence the condition of the wheel surface if the peripheral wheel speed is maintained constant, and so the optimum dressing condition is not maintained. Furthermore, there is an ever-increasing loss of production time as the work proceeds owing to the necessity of dressing the wheel more frequently as its diameter decreases.

U.S. Pat. No. 2,409,240 issued Oct. 15, 1946 discloses a method and apparatus whereby different preformed portions of an annular or cup type grinding wheel, for grinding spiral bevel and hypoid gears, are dressed with a plurality of dressing tools traversed at different constant rates for the purpose of providing different degrees of surface finish on the preformed portion of the wheel. Also disclosed is the known fact that as the traverse rate increases, the lead or pitch of the helix generated by the truing tool increases and the coarser the finish of the dressed surface becomes. Conversely, a slow traverse rate will produce a decrease in the pitch and a finer finish on the dressed surface, and a traverse rate that is to slow produces to fine a finish causing the wheel to burn the work.

However, the initial size of the preformed annular cup type wheel and portions thereof are not reduced diameterically as in the applicant's invention; but instead are reduced axially and all portions rotate at the same constant speed with no change from the initial peripheral surface speed during the life of the annular wheel. Therefore, there was no need to vary the traverse rate of any one of the dressing tools to maintain a constant pitch of the dressing tool and hence a uniform finish on the dressed surfaces of the wheel.

The present invention is based on the realization that in order to maintain the optimum dressing condition or surface finish on the wheel as the work proceeds, it is necessary to increase the velocity of traverse of the dressing tool as the wheel diameter decreases and vice versa. The velocity of traverse should, in fact, be directly proportional to the angular velocity of the wheel, that is to say, inversely proportional to the wheel diameter.

SUMMARY OF THE INVENTION

A method and device for truing a grinding wheel of a grinding machine having variable wheel drive means for maintaining a constant peripheral surface speed of the grinding wheel face. The truing device and method comprises adjustable control means such as a variable fluid flow control valve or a rheostat adjusted by means movable with and responsive to the radial distance and movement of the truing or dressing tool relative to the axis of rotation of the grinding wheel to regulate and change the speed respectively of either a reversible fluid motor or a reversible electric motor operatively connected to traverse a truing tool slide and the dressing tool together axially along the peripheral grinding face of the wheel. The speed control means is adapted for use with conventional straight, and form truing devices, with or without form bars to guide the path of the truing tool. A movable control member of the adjustable speed control means is connected to the truing tool support which is progressively advanced in predetermined increments for truing the wheel by either an automatic or a hand operated reversible truing tool feed mechanism, toward the axis of the wheel. The movable control member is adjustable relative to the truing tool support and a fixed member of the speed control means for the purpose of initially setting and calibrating the speed control means so the truing tool produces the desired truing tool pitch pattern and surface finish on the grinding face of the wheel. Thereafter the progressive incremental feed movements of the truing tool toward the wheel axis causes a corresponding number of progressive incremental movements of the movable member relative to the fixed member of the speed control means which progressively increases the traverse speed of the truing tool as the diameter and radius of the wheel is progressively decreased by the truing tool. Hence the initial predetermined desired truing tool pitch pattern, texture or finish is maintained on the grinding wheel face. Similarly, the speed control means is utilized to vary the traverse speed of a form or profile truing device adapted with a pattern or form bar, a follower fixed to the truing tool support movable radially in response to the contoured surfaces and shape of the form bar to be reproduced by the truing tool on the grinding wheel face. The truing tool is first advanced a predetermined increment radially toward the axis of the wheel to true and reduce the size of the wheel. However, as the truing tool slide is traversed axially the form bar causes varying amounts of radial movement of the follower and the truing tool toward and away from the grinding wheel axis. Hence, the speed control means automatically varies the traverse movement of the truing tool and maintains the desired uniform truing tool pitch pattern texture or surface finish on the contoured or formed grinding wheel face in accordance with changes in radial position of the truing tool relative to the axis of rotation of the wheel. The speed control means is adapted to vary the traverse speed of the truing tool at a rate which is inversely proportional to the radial distance of the truing tool from the rotational axis of the grinding wheel.

Accordingly it is one object of the invention to provide a method of dressing a grinding wheel in a precision grinding machine wherein the grinding wheel is ro-

tated about an axis at a progressively changing angular velocity in accordance with progressively changing wheel diameter so as to maintain a constant peripheral surface speed of the grinding face, which method comprises positioning a dressing tool at a predetermined radial distance from the rotational axis of the wheel and in operative relation to true the peripheral grinding face and thereby reduce the diameter of the wheel; and simultaneously adjusting speed control means in response to the radial movement of the dressing tool to control and vary the speed of the truing tool along the peripheral grinding face at a rate that is inversely proportional to the radial distance, and traversing the dressing tool in an axial direction along the peripheral grinding face at the speed inversely proportional to the radial distance of the dressing tool from the axis of wheel rotation.

Another object of the invention is to provide a truing device adapted to carry out the method in a grinding machine of the kind referred to above comprising means for supporting the dressing tool radially of and in operative relation to true the peripheral grinding face of the grinding wheel, means for positioning the dressing tool at progressively lesser radial distances from the rotational axis the wheel to dress or true and thereby progressively reduce the diameter of the wheel, means for traversing the dressing tool along the peripheral grinding face in the direction of the rotational axis of the wheel, and speed control means for determining the speed of traverse of the dressing tool including a control element movable with and responsive to the radial position of the dressing tool relative to the rotational axis for controlling and varying the speed regulating means to control the traverse speed of the dressing tool as a predetermined function of the radial position and produce a substantially constant surface finish on the grinding face as the diameter of the wheel is reduced and the angular velocity of the wheel is increased.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic representation of a dressing apparatus according to the invention, the apparatus employing a reversible linear fluid motor; and a variable fluid flow control valve for regulating the speed of the fluid motor.

FIG. 2 is a diagrammatic representation of a second dressing apparatus according to the invention, the apparatus employing a reversible electric motor and a rheostat for regulating the speed of the electric motor.

FIG. 3 is a partial view of a modified form of the invention showing how a reversible rotary fluid motor may be substituted for either the electric motor in the apparatus shown in FIG. 2, and how the gear reduction unit and the feed screw shown in FIG. 2 can be driven by the rotary fluid motor and substituted for the linear fluid motor in the apparatus shown in FIG. 1;

FIG. 4 is a partial view of another modification of the invention showing how either a fluid or an electric reversible rotary motor may be coupled directly to the feed screw shown in FIGS. 2 and 3.

FIG. 5 is a cross sectional view taken on line 5—5 of FIG. 1 showing the variable fluid flow control orifice in the speed control valve for the fluid motors.

DETAIL DESCRIPTION OF THE PREFERRED EMBODIMENTS

Each truing or dressing apparatus disclosed is diagrammatically shown, by way of example only, and is substantially a modified version of either of the truing devices disclosed, in U.S. Pat. Nos. 2,647,504 and 2,900,974 issued on Aug. 4, 1953 and Aug. 25, 1959 respectively and to which reference may be had for details not disclosed herein. The invention is also applicable to other conventional types of truing or dressing devices such as disclosed in U.S. Pat. Nos. 2,648,171 and 2,648,172 both of which issued Aug. 11, 1953. Additionally, U.S. Pat. No. 2,648,172 discloses means primarily for automatically maintaining a uniform peripheral surface speed of the wheel. Similar constant peripheral speed control means are incorporated and diagrammatically shown in FIGS. 1 and 2 of the instant invention. However, any suitable grinding wheel speed control means may be used some of which are disclosed in U.S. Pat. Nos. 2,642,703 and 2,746,214 which issued on June 23, 1953 and May 22, 1956 respectively.

Each apparatus shown is adapted for use in a precision grinding machine having a cylindrical grinding wheel X, the grinding wheel being mounted on a shaft Y for rotation about an axis Z—Z. The grinding machine in each case is of the kind in which the wheel X is rotated about the axis Z—Z at a progressively increasing or changing angular velocity or revolutions per minute in accordance with decreasing or changing wheel diameter by a variable speed wheel drive motor M regulated by speed control means such as a rheostat V operatively connected by suitable gearing to the truing tool feed mechanism. The angular velocity being inversely proportional to the wheel diameter so that the peripheral surface speed of the grinding wheel face is maintained substantially constant. The peripheral grinding face of the wheel X is dressed intermittently or periodically by means of a conventional dressing tool **10** such as, a diamond nib which, in accordance with the present invention, is traversed longitudinally along the grinding face in the axial direction at a speed which is proportional to the angular velocity of the wheel, that is, inversely proportional to the wheel diameter.

In the dressing apparatus shown in FIG. 1, the dressing tool **10** is carried at the lower end of a radially or transversely movable truing tool carrier or shaft **11** slidably mounted in a longitudinally movable tool carrier means which may include, as shown a transversely or radially movable slide **12** supported on a longitudinally or axially movable slide **14** or merely the longitudinally movable slide **14**. The tool carrier **11** is held against rotation and has a threaded portion engaging a rotatable feed nut **133** held against axial movement. A truing tool feed mechanism TF such as disclosed in U.S. Pat. No. 2,900,974 is provided for rotating the nut and moving the tool carrier **11** relative to the transverse slide **12** and the axis Z—Z so as to move the tool **10** into and out of engagement with the grinding face **13** of the wheel X. The longitudinally movable slide **14** with the transversely movable slide **12** thereon is constained to move in a longitudinal direction parallel to the axis Z—Z by means of a conventional slideway **15** on which the slide **14** is mounted, the slideway being rigidly fixed to and supported by the structure of the grinding machine indicated at **15'**.

Movement of the slide **14** in either direction along the slideway is effected by means of a reversible and variable speed linear fluid motor **16**. The motor **16** comprises a cylinder **17** whose axis extends parallel to the rotational axis Z—Z of the grinding wheel, and a piston **18** slidable in the cylinder. A rigid connector or piston rod **19** between the piston **18** and slide **14** ensures that the latter will move along the slideway in unison with the piston. Fluid under pressure is delivered to the cylinder **17** of the motor **16** via a supply line **20**, which is selectively connectible to either one of a pair of conduits leading to ports at opposite ends of the cylinder by means of a directional control valve **21**. The setting or position of the control valve **21** determines the direction in which the piston **18**, and hence the tool carrier, will move when fluid under pressure is supplied to the cylinder.

The fluid under pressure is delivered through a supply line **20** to the control valve **21** and then to the fluid motor from a fluid supply source or reservoir generally indicated at **22**, by way of a pump P and fluid exhausts through valve **21** and a speed regulator or control valve **23**. The speed control valve **23** comprises a valve housing **24** having an outlet port **25** connected to the reservoir **22** and an inlet port **26** connected to the exhaust port of valve **21**. Slidable within the valve housing **24** is a spool **27** having a slot or orifice **28** of progressively increasing or constantly varying depth between the inlet and outlet ports. The slot **28** co-operates with a spring biased needle **29** to define an orifice or restriction whose effective area is determined by the axial position of the spool **27** within the valve housing relative to the needle **29**. The setting of the needle **29** may be adjusted by means of an adjusting screw **30**.

The valve housing **24** is mounted on a bracket **31** which is rigidly mounted on the slide **14**, and one end of the spool **27** has a rack **32** with gear teeth cooperating with actuating means comprising a pinion gear **33** meshing with the rack **32** and fixed to a portion of a shaft **34** rotatably supported in the housing **24**. A portion of the shaft **34** extends out one side of the housing **24** and has a large drive gear **35** fixed to and rotatable therewith and the pinion gear **33**. An adjustable drive rack bar **36** has gear teeth in mesh with the drive gear **35** and is adjustably fixed to an end of a guide strap, support or member **37** movable within a groove, slot or guideway in a bracket **38** for axial movement with the tool carrier **11**. The rack for **36** is adjustable relative to the guide strap **37** and the tool carrier **11** by the provision of an adjusting screw and lock nut mechanism **39** shown for the purpose of calibrating and preadjusting the position of the spool **27** of the speed control valve **23** with the initial diameter and constant peripheral speed of the grinding wheel.

As the truing tool **10** is fed or moved radially by the tool carrier **11** the rack bar **36** also slides a corresponding amount along a slideway on one side of the bracket **38** and rotates the drive gear **35** which in turn rotates shaft **34** and the pinion gear **33** a portional amount and lesser number of teeth. Rotation of the pinion gear **33** moves the spool **27** relative to the needle **29** and varies the size of the orifice accordingly to vary the traverse rate of the longitudinally or axially movable truing tool slide **14** and the truing tool **10** across the grinding face **13**. Thus, the axial position of the spool **27**, and hence the effective area of the valve orifice is determined by the radial distance R of the dressing tool **10** from the rotational axis Z—Z. In practice the depth of the slot **28** increases uniformly along its length, so that the effective area of the valve orifice, and hence the driving speed of the fluid motor, is an inverse linear function of the radial distance R of the dressing tool from the axis Z—Z, that is to say an inverse linear function of the wheel diameter.

It will be noted that when the optimum dressing speed has been determined for a particular repetitive grinding operation, the needle **29** having been set by the adjusting screw **30**, the optimum conditions will be maintained in subsequent dressing operations even though the grinding wheel diameter has decreased, for the peripheral surface speed of the grinding wheel face during each traverse of the dressing tool will remain constant.

The transversely or radially movable slide **12** is supported by spaced parallel slideways, not shown, to facilitate free movement of the slide **12** relative to the longitudinally movable slide **14**. Fixed to the slide **12** is a follower **40** which is arranged to slide along an operative surface **41** of a forming bar **42**. The forming bar is shaped so as to produce a surface of predetermined shape on the operative face **13** of the grinding wheel. In case a true cylindrical grinding face **13** as shown is desired on the periphery of the grinding wheel, a forming bar **42** is provided having a plane operative face. If an irregular shape is to be produced, such as, that shown in FIG. **2**, the face **41** of the forming bar **42** is shaped to correspond with the shape to be produced on the periphery of the grinding wheel X.

The transversely movable slide **12** is preferably arranged to move radially relative to the path of movement of the longitudinally movable slide **14**. The radial slide **12** is such that either its weight or other force applied to the slide **12** together with the parts carried thereby serves yieldingly to maintain the follower **40** in operative engagement with the forming bar **42** during the longitudinal movement of the slide **14**. However in some instances the transverse or radial slide **12** may or may not be inclined as disclosed in U.S. Pat. No. 2,900,974 and conventional resilient means other than weight can be employed to bias and maintain the follower in engagement with the form bar **42**. Slide **12** is moved relative to the longitudinally movable slide **14** due to the resultant thrust of the follower **40** engaging the surface **41'** of the forming bar **42'** shown in FIG. **2** so that a vertical, angular, or curved surface may be generated or trued on the peripheral operative grinding face of the grinding wheel X in a manner similar to that disclosed in either of the U.S. Pat. Nos. 2,647,504 or 2,900,974.

As illustrated in FIG. **1** when the slide **14** is moved longitudinally, the follower **40** rides along a surface **41** on the forming bar **42** so as to true a cylindrical grinding face **13** on the grinding wheel. However, the follower **40** could be instead moving into engagement with either a curved, angled or radially extending face on another forming bar such as shown in FIG. **2** whereupon continued movement of the slide **14** produces a thrust upon the slide **12** to move it generally in a radial direction so that the follower **40** and the truing tool **10** therewith follows the surface **41'** to true a corresponding shape on the grinding wheel.

The opposite ends of the piston **18** are preferably of equal surface area but may have different surface area and therefore will travel at one speed as it moves to the

right and at a different speed as it moves toward the left back to the initial starting position. However, the area of the opposite end faces of the piston **18** can be equalized by providing another piston rod **19***a* of the same cross sectional area as the piston rod **19** or extending the piston rod **19**, as shown in FIG. **1**. In some instances it may be desirable to first traverse the truing tool **10** at a faster or rough truing rate on the first pass and at a slower or fine truing rate on the return or second finishing pass of the truing tool across the grinding face **13**.

Therefore, in any desired arrangement or sequence of operation, it is obvious that the speed control valve **23** is preferably calibrated and connected into the fluid control system so that it dominates over any other throttle valve which may be utilized and determines the final traverse rate of the last or final finishing pass of the truing tool determining the desired surface finish on the grinding face and the workpiece ground thereby during each truing cycle.

The second dressing apparatus shown in FIG. **2** is basically similar to that of FIG. **1**, and corresponding parts thereof are denoted by the same reference numerals. In this embodiment the tool carrier means or the longitudinal movable slide **14** is driven along the slideway **15** at a predetermined speed by means of a reversible direct current electric motor **63** having a rotary output or drive shaft **64**, the rotary output shaft being connected to drive the slide **14** through a speed reduction means **65** such as, a worm and worm gear shown coupled to a rotatable feed screw or screw-threaded shaft **66** which engages a conventional internally threaded nut, sleeve or collar not shown fixed to the slide **14**. The feed screw **66** is journalled at its opposite ends in bearings **67, 68** carried by the slideway **15** and the fixed structure **15'** of the grinding machine.

The motor **63** is preferably a direct current shunt motor. The speed of the motor is regulated by means of a speed regulating electrical circuit, the speed control means of which is a conventional rheostat **70** having usually a movable contact element engaging a resistance element to vary the resistance and electrical current to the motor. The setting of the rheostat, like the setting of the valve spool **27** in the preceding embodiment, is determined by the radial distance R of the dressing tool **10** from the axis Z—Z. To this end the tool carrier **11** is connected by the rigid guide strap **37** to actuating means comprising a rack bar **72** which has gear teeth meshing with a drive gear **73** of a predetermined proportional diameter to provide the desired control of the rheostat **70**. The gear **73** is rotatably mounted on the bracket **31** fixed to the slide **14** and operatively connected by any suitable means such as a flexible shaft to the rotary shaft and movable contact element of the rheostat **70**. The rheostat is linearly wound, and therefore the motor supply current is an inverse linear function of the radial distance R of the tool **10** from the axis Z—Z. The speed of motor **63** which determines the speed of traverse of the dressing tool **10**, is therefore an inverse linear function of the diameter of the grinding wheel X. In order to calibrate or preset the dressing speed to produce the desired surface finish on the grinding face **13** of a wheel of given diameter and produce the optimum value for a particular sequence of grinding operations, the position of the rack **72** relative to the tool carrier **11** is initially set by means of an adjusting screw mechanism **74**, which interconnects the strap **37** and the rack **72**.

As illustrated in the drawing, the motor supply lines are connected to the speed regulatory circuit by way of a reversing switch **76**. Alternatively, however, the motor **63** may be unidirectional, reverse movement of the tool carrier being effected by any suitable conventional reversing drive mechanism, such as, a reversible gearing not shown.

One example of applying the invention to form truing or dressing the grinding face **13** of the grinding wheel X is shown in FIG. **2** wherein a form bar **42'** has a follower engaging surface **41'** of different shape than that shown on the form bar **42** of FIG. **1**. The specific shape shown is only one example of the many possible shapes which may be reproduced on the grinding wheel face **13**. The grinding wheel X formed to the shape shown has essentially a plurality of step like portions of different diameters and radial distances from the axis Z—Z. Thus, the truing tool **10**, carrier **11**, and rack **72** are moved radially various amounts toward and away from axis Z—Z in response to the radial movement of the follower **40** and the transversely movable slide **12** whereby the gear **73** and rheostat **70** are rotated various amounts in different directions to vary the traverse rate accordingly to produce and maintain the same or constant surface finish on each of the wheel portions of different diameter.

Referring to FIG. **3**, there is shown a portion of the traversing mechanism disclosed in FIG. **2** driven by a conventional reversible rotary fluid or hydraulic motor RFM which may be substituted for either the reversible electric motor **63** or the reversible linear fluid or hydraulic motor **16**, and connected to, operated and controlled by the speed control valve **23** in the manner disclosed in FIG. **1**. It is obvious that each of the fluid conduits connected to the opposite ports of the linear fluid motor **16** can be reconnected to the operating ports of the rotary reversible fluid motor RFM suitably fixed to the slideway **15** and structure **15'**. Shifting of the spool in the directional control valve **21** in one direction directs fluid under pressure to one or the other of the ports in either one of the fluid motors utilized and traverses the slide **14** and the truing tool **10** in one direction. When the spool is shifted in the opposite direction the fluid is directed to the opposite port and reverses the directions of fluid flow to traverse the slide **14** and the truing tool **10** in the opposite direction.

Another modification is shown in FIG. **4** wherein a reversible rotary drive motor DM, which may be either the rotary fluid motor RFM or the electric motor **63** disclosed, is coupled directly to the traversing feed screw **66**. Obviously, if the motor DM is of the fluid type it would be connected to and controlled by the control valve **23** in the system and manner disclosed in FIG. **1** and if electric, it would be connected to and controlled by the rheostat **70** in the system and manner disclosed in FIG. **2**.

In FIG. **5** there is shown in cross section an end of the spool **27** and the slot **28** which increases in depth at a predetermined progressively uniform rate and slope relative to the position of the needle valve **29**. The slot **28** shown has V-shape surfaces mating with corresponding V- or cone-shape surfaces on the needle **29** which may be adjusted to provide between them the size orifice which determines the desired traverse rate of the slide **14**.

In operation the speed controlled truing devices shown and described above are first preset or reset by turning the handwheel **107**, pinion gear **106**, feed gear **100**, and feed nut **133** to retract the truing tool carrier **11** and the truing tool **10** away from the axis Z—Z sufficiently to attach a new full size grinding wheel X onto the spindle Y of the grinding machine. Rotation of feed gear **100** and feed nut **133** rotates or causes rotary movement of pinion gear **108** operatively connected through suitable reduction gearing to reset the rheostat V and reduce the speed of the drive motor M to provide the desired initial predetermined constant peripheral surface speed of the wheel face **13**. Retraction of the tool carrier **11** also resets the guide strap **37**, the rack bars **36** and **72** which rotate the gears **33** and **35**, and **73**, to reset the spool **27** in valve **23** and the rheostat **70** respectively to slow down the reversible fluid motors **16** or RFM, and electric motor **63**.

It is assumed that the speed control valve **23** and the rheostat **70** have been calibrated to the diameter of the wheel X by adjusting the position of rack bars **36** and **72** relative to the guide strap **37**, truing tool carrier **11**, and truing tool **10**, and the needle **29** has been adjusted and fixed in position by the adjusting screw **30** to traverse the truing slide at the desired rate.

It is also assumed that the grinding wheel X is being driven by wheel drive means including motor M, power is available to line L1, switch SW1 has been closed, and pump P is being driven and supplying fluid under pressure.

The truing tool **10** can now be advanced a predetermined increment toward the axis Z—Z in any suitable well known manner such as by turning the handwheel **107** by hand or automatically actuating the truing tool feed mechanism TF in the manner disclosed in the U.S. Pat. No. 2,900,974. A predetermined amount or increment of rotation of the handwheel in the proper direction or actuation of the feed mechanism rotates the nut **133**, fixed against axial movement about the screw threaded portion of the tool carrier **11** fixed against rotation, to feed the truing tool the desired amount toward the axis Z—Z. Movement of the tool carrier **11** and the tool **10** causes a simultaneous corresponding movement of the rack bars **36** and **72** toward the axis Z—Z. Movement of the rack bar **36** toward the axis Z—Z causes rotary movement of the gears **33** and **35** to shift spool **27** relative to the needle valve **29** to increase the size of the orifice an amount which will increase fluid flow and the speed of any of the fluid motors **16**, or RFM to compensate for the subse-quent reduction in radius and diameter of the grinding wheel X. Simultaneous rotation of gear **100**, **108**, and rheostat V causes an increase in the speed of the motor M to compensate for what would otherwise cause a reduction in peripheral speed, due to a subsequent decrease in diameter, and radius of the grinding wheel X. Likewise movement of the rack bar **72** toward axis Z—Z rotates gears **73** and **108** and hence rheostat **70** and V an amount which will increase the speed of electric motor **63** and M to compensate for the subsequent reduction in diameter, radius, and maintain a constant peripheral surface speed of and surface finish on the grinding wheel face.

The truing cycle is now ready to be performed in the usual manner and the various motor speed control devices have been calibrated or readjusted and preadjusted to maintain both the desired constant peripheral surface speed and constant surface finish of the grinding face regardless of the diameter and radius to which wheel is being dressed to grind workpieces.

Referring to FIG. **1**, closing a switch SW2 either automatically or manually, energizes a solenoid S2 which shifts the spool in control valve **21** to the right. Fluid such as a hydraulic fluid under pressure from line or conduit **20** passes through a line or conduit connected to the left hand side or one side of either the reversible linear fluid motor **16** or rotary fluid motor RFM which may be substituted therefor and to the tool feed mechanism TF. Truing tool **10** is advanced an increment toward axis Z—Z, valve **23** and rheostat V are readjusted accordingly before truing tool **10** contacts wheel face **13**. The longitudinally movable slide **14** together with the speed control valve **23**, transversely movable slide **12**, follower **40**, truing tool carrier **11**, and the truing tool **10** are traversed toward the right with the follower **40** in engagement with the surface **41** of the form bar **42**. In this case the transversely movable slide **12**, the truing tool carrier **11**, and truing tool **10** carried thereby has no radial movement relative to slide **14** because the surface **41** of the form bar **42** is parallel to the axis Z—Z. Therefore, the truing tool **10** will pass axially over and dress the grinding face parallel to the axis Z—Z at a speed controlled by the size of the orifice in valve **23**. Fluid exhausts from the right hand end or opposite end of the linear fluid motor **16** or rotary motor RFM through the calibrated flow control orifice between V surfaces of the slot **28** and needle **29** of the speed control valve **21** to the reservoir **22**. Movement to the right is arrested by either a stop not shown or bottoming of the piston **18** in cylinder **17**.

The truing device operates in a similar manner to reverse the direction of traverse by either manually or automatically opening SW2 and closing SW3 to de-energize S2 and energize solenoid S3. Solenoid S3 shifts spool in valve **21** toward the left and directs fluid under pressure to the right hand end or opposite end of the fluid motor **16** or RFM. Valve **2** also, simultaneously actuates the feed mechanism TF, to advance the truing tool **10** toward axis Z-Z which shifts the spool in valve **27** to increase the size of the orifice in valve **23** and readjusts the rheostat V. These movements increase the speed of either the fluid motors **16** or RFM and wheel drive motor M accordingly in the manner described to maintain the desired constant peripheral surface speed and dressed surface finish on the grinding wheel face **13**.

Referring to FIG. **2** wherein the truing apparatus is provided with a contoured form bar **42'** which may also be of the plain type shown in FIG. **1**. With form bar **42'** the transversely movable slide **12** together with the truing tool carrier **11** and the truing tool **10** thereon will be moved toward and away from the axis Z—Z in response to the radial movement of the follower **40** as it traverses over the contoured surface **41'**. Either the hand wheel **107** or feed mechanism TF is actuated as taught above to advance the tool **10** a predetermined increment toward axis Z—Z which adjusts the rheostats V and **70** to increase the speed of motors M and **63** accordingly.

Closing the F contacts of the reversing switch **76** connects L1 to rotate the motor **63** in one direction which rotates the gear reduction mechanism **65** and/or the feed screw **66** in a direction that traverses the slide **14** toward the right at a speed controlled by the rheostat

70. The rheostats 70 and V may be preadjusted or calibrated to any one of the initial different diameters to be trued on the grinding wheel X and both of the rheostats V and 70 will automatically be readjusted as the truing tool carrier 11 and truing tool 10 moves radially in response to the movement of follower 40 to reproduce the form on the grinding face 13.

Thus any radial movement away from the axis Z—Z causes a corresponding simultaneous readjustment of the speed control devices disclosed to slow down the speed of the fluid or electric motors and the traverse rate of the slide 41 and the truing tool 10. Conversely any movement toward the axis Z—Z readjusts the speed control devices to speed up the fluid and electric motors and the traverse rate of the slide and truing tool.

A truing cycle may consist of one or two passes of the truing tool over the grinding face of the grinding wheel. The first pass may be, if desired, a rough dressing and the second or return pass the finishing pass wherein the truing tool feed increment is less than that for rough dressing.

The truing apparatus shown in FIG. 2 may be reversed, after actuating the truing tool feed mechanism TF again as taught above by moving the reversible switch 76 so as to close the contacts R whereby the rotation of the motor 63 and the screw 66 are reversed to traverse the slide 14 together with transversely movable slide 12, the follower 40, the truing tool carrier 11, truing tool 10, and the speed control pinions 108, 73 and rack bar 72 toward the left.

Although specific embodiments of the invention have been described and diagrammatically illustrated herein, it should be noted that alternative arrangements and embodiments may also be feasible without departing from the spirit of the invention or the scope of the following claims directed thereto. It is clear that the apparatus and method hereinbefore described represent a distinct advance in the art which is capable of benefiting industry generally.

What is claimed is:

1. In combination with a grinding machine having
a grinding wheel with a peripheral grinding face rotatably supported for rotation about an axis of rotation;
means for rotating and progressively changing angular velocity of the grinding wheel in accordance with changing grinding wheel diameter to maintain a substantially constant peripheral surface speed of the grinding face;
means for dressing the grinding face including
a tool carrier movable toward and away from the axis of rotation,
a dressing tool on and movable with the tool carrier,
tool carrier means for supporting the tool carrier and the dressing tool movable relative to and into operative relation to dress and peripheral grinding face of the grinding wheel to a predetermined shape,
means for feeding the tool carrier and the dressing tool a predetermined increment relative to the tool carrier means, the grinding face, and toward the axis of rotation to dress and thereby reduce the diameter of the grinding wheel accordingly,
means for traversing the tool carrier means and the dressing tool across the grinding face in a longitudinal direction of the axis of rotation of the grinding wheel; wherein the improvement comprises:
variable drive means operatively connected to the means for traversing the dressing tool; and
speed control means operatively connected to the variable drive means and responsive to radial movement and distance of the dressing tool from the axis of rotation of the grinding wheel for determining a speed and varying the speed of the variable means for traversing the truing tool as an inverse function of changes in the radial distance of the truing tool from the axis of rotation of the grinding wheel.

2. The combination according to claim 1 wherein the variable drive means for traversing the dressing tool comprises:
a reversible fluid motor operatively connected to the tool carrier means;
means for supplying and conveying fluid under pressure to drive the fluid motor; and
directional control means for selectively directing the fluid under pressure to drive the reversible fluid motor in opposite directions.

3. The combination according to claim 1 wherein the variable drive means comprises:
a reversible variable speed electric motor having a drive shaft operatively connected to the tool carrier means;
means for supplying and conveying electrical energy to drive the electric motor; and
directional control means for selectively directingthe electrical energy to drive the reversible electric motor in opposite directions of rotation.

4. In combination with a grinding machine having
a grinding wheel with a peripheral grinding face rotatably supported for rotation about an axis of rotation;
means for rotating and progressively changing angular velocity of the grinding wheel in accordance with changing grinding wheel diameter to maintain a substantially constant peripheral surface speed of the grinding face;
means for dressing the grinding face including
a tool carrier movable toward and away from the axis of rotation,
a dressing tool on and movable with the tool carrier,
tool carrier means for supporting the tool carrier and the dressing tool movable relative to and into operative relation to dress the peripheral grinding face of the grinding wheel to a predetermined shape,
means for feeding the tool carrier and the dressing tool a predetermined increment relative to the tool carrier means, the grinding face, and toward the axis of rotation to dress and thereby reduce the diameter of the grinding wheel accordingly,
means for traversing the tool carrier means and the dressing tool across the grinding face in a longitudinal direction of the axis of rotation of the grinding wheel; wherein the improvement comprises:
variable drive means operatively connected to the means for traversing the dressing tool;
speed control means operatively connected to the variable drive means and responsive to radial movement and distance of the dressing tool from the axis of rotation of the grinding wheel for determining a speed and varying the speed of the

variable means for traversing the truing tool to maintain and repeatedly produce a substantially constant uniformly dressed surface finish on the grinding face during the life of the wheel in accordance with the changes in the radial distance of the truing tool from the axis of rotation and diameter of the grinding wheel;

said variable drive means for traversing the dressing tool comprises:

a reversible fluid motor operatively connected to the tool carrier means;

means for supplying and conveying fluid under pressure to drive the fluid motor; and

directional control means for selectively directing the fluid under pressure to drive the reversible fluid motor in opposite directions; and

said speed control means comprises:

a fluid flow control valve having

a valve housing,

an inlet port, and

an outlet port spaced from the inlet port;

a speed control member in and movable relative to the housing and having

an orifice of constantly varing area extending between the inlet and the outlet ports; and

actuating means connected to and responsive to radial movement and position of the tool carrier and the dressing tool relative to the axis of rotation for causing relative movement between the housing and the speed control member and changing the area of the orifice, flow of fluid through the orifice, and the speed of the fluid motor in response to the radial movement and position of the dressing tool relative to the axis of rotation.

5. In combination with a grinding machine having

a grinding wheel with a peripheral grinding face rotatably supported for rotation about an axis of rotation;

means for rotating and progressively changing angular velocity of the grinding wheel in accordance with changing grinding wheel diameter to maintain a substantially constant peripheral surface speed of the grinding face;

means for dressing the grinding face including

a tool carrier movable toward and away from the axis of rotation,

a dressing tool on and movable with the tool carrier,

tool carrier means for supporting the tool carrier and the dressing tool movable relative to and into operative relation to dress the peripheral grinding face of the grinding wheel to a predetermined shape,

means for feeding the tool carrier and the dressing tool a predetermined increment relative to the tool carrier means, the grinding face, and toward the axis of rotation to dress and thereby reduce the diameter of the grinding wheel accordingly,

means for traversing the tool carrier means and the dressing tool across the grinding face in a longitudinal direction of the axis of rotation of the grinding wheel; wherein the improvement comprises:

variable drive means operatively connected to the means for traversing the dressing tool;

speed control means operatively connected to the variable drive means and responsive to radial movement and distance of the dressing tool from the axis of rotation of the grinding wheel for determining a speed and varying the speed of the variable means for traversing the truing tool to maintain and repeatedly produce a substantially constant uniformly dressed surface finish on the grinding face during the life of the wheel in accordance with the changes in the radial distance of the truing tool from the axis of rotation and diameter of the grinding wheel,

said variable drive means for traversing the dressing tool comprises:

a reversible fluid motor operatively connected to the tool carrier means;

means for supplying and conveying fluid under pressure to drive the fluid motor; and

directional control means for selectively directing the fluid under pressure to drive the reversible fluid motor in opposite directions; and

said speed control means comprises:

a fluid flow control valve having

a valve housing, fixed against radial movement relative to the axis of rotation, attached to and movable with the tool carrier means in the longitudinal direction having

a bore in the housing,

an inlet port in the housing leading into the bore,

an outlet port in the housing leading from the bore;

a speed control member movable in the bore relative to the housing and having

a slot of constantly varying depth extending between the inlet and outlet ports in the housing;

a needle member in the valve housing having

an end portion extending into the slot and providing an orifice between the speed control member and the needle of a size determined by the position of the speed control member relative to the needle and through which the fluid flows at a rate determining the speed of the fluid motor and the dressing tool across the grinding face; and

actuating means connected to the tool carrier and the speed control member for shifting the speed control member relative to the needle and changing the size of the orifice in response to the radial movement and position of the tool carrier and dressing tool relative to the axis of rotation.

6. The combination according to claim **5** wherein the actuating means comprises:

a rack bar with gear teeth thereon fixed to and movable with the tool carrier relative to the axis of rotation of the grinding wheel;

a drive gear with gear teeth meshing with the gear teeth on the rack bar and rotatably mounted on the housing; and

a driven gear fixed to and rotatably driven by the drive gear and having gear teeth meshing with rack teeth on the speed control member.

7. The combination according to claim **6** wherein the reversible fluid motor is a linear fluid motor comprising:

a cylinder,

a piston slideable in the cylinder; and

a piston rod connected to the piston and the tool carrier means.

8. The combination according to claim 6 wherein the variable drive means comprises:
a reversible rotary fluid motor having
a rotatable drive shaft; and
a rotatable feed screw coupled to the drive shaft and threadedly engaging tool carrier means for traversing the dressing tool across the grinding face.

9. The combination according to claim 8 wherein the variable drive means further comprises:
a gear reduction mechanism coupled to the drive shaft and the feed screw.

10. In combination with a grinding machine having a grinding wheel with a peripheral grinding face rotatably supported for rotation about an axis of rotation;
means for rotating and progressively changing angular velocity of the grinding wheel in accordance with changing grinding wheel diameter to maintain a substantially constant peripheral surface speed of the grinding face;
means for dressing the grinding face including
a tool carrier movable toward and away from the axis of rotation,
a dressing tool on and movable with the tool carrier,
tool carrier means for supporting the tool carrier and the dressing tool movable relative to and into operative relation to dress the peripheral grinding face of the grinding wheel to a predetermined shape,
means for feeding the tool carrier and the dressing tool a predetermined increment relative to the tool carrier means, the grinding face, and toward the axis of rotation to dress and thereby reduce the diameter of the grinding wheel accordingly,
means for traversing the tool carrier means and the dressing tool across the grinding face in a longitudinal direction of the axis of rotation of the grinding wheel; wherein the improvement comprises:
variable drive means operatively connected to the means for traversing the dressing tool;
speed control means operatively connected to the variable drive means and responsive to raidal movement and distance of the dressing tool from the axis of rotation of the grinding wheel for determining a speed and varying the speed of the variable means for traversing the truing tool to maintain and repeatedly produce a substantially constant uniformly dressed surface finish on the grinding face during the life of the wheel in accordance with the changes in the radial distance of the truing tool from the axis of rotation and diameter of the grinding wheel;
said variable drive means comprises:
a reversible variable speed electric motor having
a drive shaft operatively connected to the tool carrier means;
means for supplying and conveying electrical energy to drive the electric motor; and
directional control means for selectively directing the electrical energy to drive the reversible electric motor in opposite directions of rotation; and
said speed control means comprises:
an electrical control circuit;
a rheostat connected to the electrical circuit and having a variable resistance element connected electrically to the electrical motor, and
a movable contact element engaging and movable relative to the resistance element;
actuating means connected to the tool carrier and the movable contact element for shifting the movable contact element relative to the resistance element to vary the resistance and rotational speed of the electric motor and the dressing tool across the grinding face in response to the radial movement and position of the tool carrier and dressing tool relative to the axis of rotation.

11. The combination according to claim 10 wherein the variable drive means further comprises:
a rotatable feed screw coupled to the drive shaft of the electric motor and threadedly engaging the tool carrier means for traversing the dressing tool across the grinding face.

12. The combination according to claim 11 wherein the variable drive means further comprises:
a gear reduction mechanism coupled to and situated between the drive shaft of the electric motor and the feed screw.

13. An apparatus for dressing the peripheral grinding face of a grinding wheel with a dressing tool, said apparatus comprising means for rotating the grinding wheel about its central axis, motor means for moving the dressing tool across the face of the grinding wheel as it is being rotated, and control means for varying the speed at which said motor means moves the dressing tool across the face of the grinding wheel as an inverse function of variations in the distance between the dressing tool and the axis of rotation of the grinding wheel.

14. An apparatus as set forth in claim 13 wherein said motor means includes a fluid motor, and said control means includes conduit means for conducting fluid to and from said fluid motor and means for varying the rate of fluid flow through said conduit means as a function of variations in the distance between the dressing tool and the axis of rotation of the grinding wheel.

15. An apparatus for dressing the peripheral grinding face of a grinding wheel with a dressing tool, said apparatus comprising means for rotating the grinding wheel about its central axis, motor means for moving the dressing tool across the face of the grinding wheel as it is being rotated, said motor means including a fluid motor, and control means for varying the speed at which said motor means moves the dressing tool across the face of the grinding wheel as a function of variations in the distance between the dressing tool and the axis of rotation of the grinding wheel, said control means including conduit means for conducting fluid to and from said fluid motor and means for varying the rate of fluid flow through said conduit means as a function of variations in the distance between the dressing tool and the axis of rotation of the grinding wheel, said means for varying the rate of fluid flow through said conduit means includes means for defining an orifice of variable cross-sectional area and means for varying the cross-sectional area of said orifice as a function of variations in th distance between the dressing tool and the axis of rotation of the grinding wheel.

16. An apparatus for dressing the peripheral grinding face of a grinding wheel with a dressing tool, said apparatus comprising means for rotating the grinding wheel about its central axis, motor means for moving the

dressing tool across the face of the grinding wheel as it is being rotated, said motor means including an electrical motor, and control means for varying the speed at which said motor means moves the dressing tool across the face of the grinding wheel as a function of variations in the distance between the dressing tool and the axis of rotation of the grinding wheel, said control means including electrical circuit means for conducting electrical energy to said electric motor and means for varying the rate at which electrical energy is conducted to said electrical motor as a function of variations in the distance between the dressing tool and the axis of rotation of the grinding wheel.

17. An apparatus as set forth in claim **16** wherein said means for varying the rate at which electrical energy is conducted to said electrical motor includes a rheostat and means for actuating said rheostat to an extent which varies as a function of variations in the distance between the dressing tool and the axis of rotation of the grinding wheel.

18. An apparatus for dressing the peripheral grinding face of a circular grinding wheel with a dressing tool, apparatus comprising tool holder means for supporting the dressing tool for movement toward and away from a central axis of the grinding wheel and for supporting the dressing tool for movement along a path extending parallel to the face of the grinding wheel, first motor means for rotating the grinding wheel about its central axis, first control means for varying the rotational speed at which said first motor means rotates the grinding wheel as a function of variations in the diameter of the grinding wheel to maintain the peripheral speed of the face of the grinding wheel substantially constant, second motor means for moving said toolholder means along said path to move dressing tool across the face of the grinding wheel, and second control means for varying the speed at which said second motor means moves said toolholder means and dressing tool across the face of the grinding wheel as a function of variations in the diameter of the grinding wheel to maintain a substantially uniform finish on the face of the grinding wheel with changes in diameter of the grinding wheel.

19. A method of repeatedly dressing a substantially constant uniform surface finish on a peripheral grinding face of a circular grinding wheel, said method comprising the steps of rotating the grinding wheel about an axis of rotation, repeatedly dressing the grinding wheel by repeatedly moving a dressing tool transversely across the face of the grinding wheel while it is being rotated, maintaining the peripheral speed of the grinding wheel face constant as the diameter of the grinding wheel decreases due to the repeated dressing of the grinding wheel by increasing the angular velocity of rotation of the grinding wheel as the grinding wheel diameter decreases, and maintaining a substantially constant uniform surface finish on the face of the grinding wheel as the diameter of the grinding wheel decreases and the angular velocity of rotation of the grinding wheel increases by increasing the speed at which the dressing tool is moved across the face of the grinding wheel as a function of variations in the diameter of the grinding wheel.

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